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ASYMMETRIC STARK SHIFT IN InAs/GaInAsP(Q_{1.18}) QUANTUM DOTS GROWN ON (311)B InP SUBSTRATE

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Abstract : We present photocurrent (PC) spectroscopy of InAs/InGaAsP (Q_{1.18}) quantum dots (QD) embedded in a PIN diode grown on InP(311)B substrate. From 300K and 77K spectra we deduce the transition energies for ground state of the dots. These energies are sensitive to applied bias and reveal an asymmetric quantum-confined Stark shift (QCSS) attributed to the presence of a strain-induced field in the dots.

1 Introduction

Quantum-confined Stark shift (QCSS) has been mostly experimentally studied on InAs/GaAs QD [1,2]. Numerical simulation investigations of carrier energy levels in InAs quantum dots (QD) on InP substrate have been performed in our laboratory [3] that emphasizes the importance of substrate orientation. We present a photocurrent (PC) spectroscopy investigation of the QCSS of InAs/InGaAsP (Q_{1.18}) QD grown on InP(311)B substrate. Self-assembled InAs/InGaAsP(Q_{1.18}) QD were grown by molecular beam epitaxy on InP(311)B substrate. The height of the dots (2.6 nm) was controlled by the double cap procedure [4]. One plan of dot was encapsulated in a PIN structure (Fig. 1).

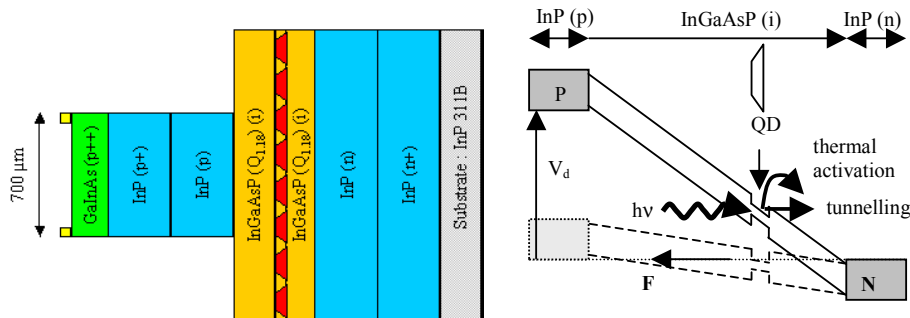


Fig. 1: PIN diode structure (Left) and energy band diagram (Right).

The mesa profile allows very low dark current in the reverse bias regime. Large electric fields could be applied with negligible dark current ($< 1\text{ nA}$) at 77 K: $F = (V_d + V_{bi})/W_i = 526\text{ kV/cm}$ where $V_d = 4\text{ V}$ is the applied reverse bias, V_{bi} the built-in potential (1.4 V at 77 K) and $W_i = 102.6\text{ nm}$ the width of the intrinsic region). For reverse bias, F points from the bottom to the top of the dots.

2 Photocurrent spectroscopy

We present photocurrent spectra at 300 K and 77 K for applied bias $V_d = 0$ (Fig. 2(left)). From these measurements we deduce the fundamental transition energies of the dots $E_{\sigma}(300\text{ K}) = 0.783\text{ eV}$ ($\lambda = 1.583\text{ }\mu\text{m}$) and $E_{\sigma}(77\text{ K}) = 0.829\text{ eV}$ ($\lambda = 1.495\text{ }\mu\text{m}$). These energy levels are consistent with numerical simulation of InAs QD on InP(311)B substrate [3] and high excitation power photoluminescence [5]. The temperature shift ($\Delta E_{\sigma} = 40\text{ meV}$) is in agreement with the gap variation determined by Varshny Law.

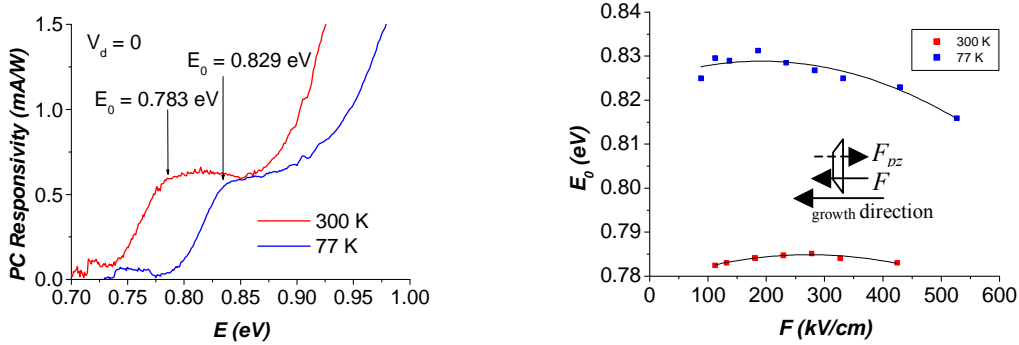


Fig. 2: (left) 300 K and 77K photocurrent spectra for applied bias $V_d = 0$. (right) 300 K and 77K ground state transition energies E_0 versus electric field F . Solid lines are fit with the law $E_0(F) = E_0(0) - \alpha F - \beta F^2$.

In order to investigate the Stark shift we measured PC spectra as function of the applied electric field. The results show a pronounced asymmetry of the ground state transition energy QCSS (Fig. 2(right)). This asymmetry is consistent with a piezoelectric field F_{pz} elongated along the growth direction and pointing from the top to the bottom of the dots. The orientation and the strength (Fig. 2(right)) of the observed piezoelectric field F_{pz} is in agreement with experimental observation on InAs/GaAs(311)B QD [1] and numerical predictions for strain-induced field in QD grown on (311)B substrates [3]. Contrary to ref [2], no inversion of F_{pz} due to composition gradient was seen.

We fit the QCSS with the following law: $E_0(F) = E_0(0) - \alpha F - \beta F^2$ where α is the ground state dipole moment and β the polarizability of the ground state electron and hole wave functions. From the dipole moment value α we deduce a hole–electron separation $z_h - z_e = \alpha/e = -4 \pm 1 \text{ \AA}$, where z is the growth direction.

Temperature (K)	$E_0(0)$ (eV)	α (C.cm)	β (C.cm ² /V)	F_{pz} (kV/cm)
300	0.778 ± 0.001	$-(7.7 \pm 0.5) \cdot 10^{-27}$	$(1.39 \pm 0.04) \cdot 10^{-32}$	-270 ± 10
77	0.825 ± 0.003	$-(7 \pm 2) \cdot 10^{-27}$	$(1.86 \pm 0.05) \cdot 10^{-32}$	-190 ± 40

Table 1: Fitting parameters of QCSS with the law $E_0(F) = E_0(0) - \alpha F - \beta F^2$.

3 Conclusion

Photocurrent versus applied field measurements of InAs/InGaAsP ($Q_{1,18}$) quantum dots (QD) embedded in a PIN diode on InP(311B) give access to the quantum-confined Stark shift of the ground state transition energy in the dots. The asymmetry of this quantum-confined Stark shift (QCSS) is attributed to the presence of a strain-induced field in the dots as predicted by numerical calculation for (311)B substrates and observed on InAs QD grown on (311)B GaAs substrates.

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